Participation of mathematics and physics students in multidisciplinary challenge-based education at the end of a bachelor program

PARTICIPATION OF MATHEMATICS AND PHYSICS STUDENTS IN MULTIDISCIPLINARY CHALLENGE-BASED EDUCATION AT THE END OF A BACHELOR PROGRAM

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ABSTRACT

Many universities introduced Challenge-Based Education (CBE) as a way to innovate engineering education. Typically, in CBE students develop and use their knowledge in order to solve real-world problems in society, in multi-disciplinary groups and often in collaboration with external stakeholders. For departments of mathematics and physics innovations such as CBE are often not straightforward. In their strive for depth, they struggle for example with the multi-disciplinary nature of CBE. This study focused on the Bachelor Final Project in an innovation lab (IBFP) at a university of technology in the Netherlands. We have investigated the affordances and constraints for mathematics and physics students to participate in such IBFPs, and how these can be understood in terms of successful innovations in engineering education. Students from all departments can participate in IBFP, but mathematics and physics students have been practically absent. We investigated the reasons for this absence by studying university documents and interviewing stakeholders (N=13). We identified themes emerging from this data, which show that organizational issues played a role, but also factors related to educational innovations and the particular nature of mathematics

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and physics education. The study helps to understand innovation efforts towards CBE, involving mathematics and physics students.

1 INTRODUCTION

1.1 Section 1

Many universities have introduced Challenge-Based Education (CBE) as a strategy to innovate engineering education. Typically, in CBE students develop and use their knowledge in order to solve real-world problems in society, in multi-disciplinary teams and often in cooperation with external stakeholders [1]. It is expected that CBE fosters student motivation and that they will develop skills, important for future engineering work: working with stakeholders, collaborating in multidisciplinary teams, identifying and analysing relevant problems, and designing (prototype) solutions [2].

The introduction of CBE to a university or a department implies a curriculum innovation. However, it is complex and demanding to create successful and lasting innovations in engineering education [3]. Graham [4] identified key characteristics of successful change in undergraduate engineering education, based on interviews and selected case studies. Effective innovations have tended to focus on connecting learning with authentic professional engineering contexts and a student-centred pedagogy, such as problem-based or project-based learning, and arguably CBE, due to its connection with these approaches [5].

Departments of mathematics and physics, typically have a special position in universities of technology, because these two disciplines are of a more fundamental nature than the traditional engineering disciplines, such as mechanical and electrical engineering [6]. Essentially, mathematics is an abstract and pure science, and not just a service subject to help engineers carry out their calculations. Also questions in physics are often indirectly rather than directly connected to problems experienced in society. Hence, for departments of mathematics and physics the introduction of innovations such as CBE is not straightforward.

The study described in this paper focuses on the participation of mathematics and physics students in an innovative CBE experience at a university of technology in the Netherlands. In this university's educational vision, CBE plays an important role. One CBE opportunity created for students is the Bachelor Final Project at an innovation lab at the university (IBFP). In the IBFPs, students work together in multi-disciplinary teams (e.g. industrial design, mechanical engineering, innovation sciences) on a challenge, set by a stakeholder from outside the university. The one-semester projects take place at the end of the students' three year bachelor programmes.

At this technical university it was noted that students from the mathematics and physics bachelor programmes had been practically absent from the IBFPs. The goal of this study was to investigate the reasons for this absence.

We pose the following research questions:

1. What are the affordances and constraints that stakeholders perceive for mathematics and physics students to choose and participate in an IBFP?

2. How can these affordances and constraints be understood from the perspective of success factors regarding innovation in engineering education?

After this introduction, we first outline the theoretical frames used: Challenge-Based Education, and innovation in engineering education. Second, we describe in more detail the context in which the study took place and the research methods we used. Third, we present the results, and fourth, our conclusions.

2 THEORETICAL FRAMES

In this section the theoretical frames used in this paper are explained: Challenge-Based Education (CBE), and successful change in engineering education.

2.1 Challenge-Based Education

In CBE “grand challenges” are offered to students, from which they themselves identify a particular problem they will address. Students typically design and create a prototype solution to the problem in multidisciplinary groups [1]. CBE is considered a student-centered learning (and teaching) approach, where students are actively involved in choosing and developing their own learning trajectory. The challenges are often connected to big issues that need to be addressed to ensure the sustainability of human societies. During their work on the project, participants realize the value of different perspectives, critical thinking and reflection. In this way, CBE experiences can engage students in ways of thinking and learning authentic to the engineering profession, which is said to contribute to deeper learning and meaning making than traditional lecture-based courses [7].

CBE changes the roles of both the teacher and the student. Students need to become more self-regulated learners. Their work is guided by tutors, process and academic coaches and often by external *challenge owners*, who adopt the role of a coach and co-experimenter, instead of a knowledge provider. The challenge owners are people from industry or from within the university who have proposed the grand challenge, and they are stakeholders in the solution. With different parties involved, collaboration in the team of educators and stakeholders becomes important.

CBE in mathematics or physics at university level is scarcely reported in the research literature. Mathematics and physics can be considered fundamental subjects that study particular phenomena in depth. However, in the practice-oriented CBE projects, mathematics (and to a lesser extent physics) are often seen as tools for the engineering sciences. Dahl [6] claims that the knowledge created in mathematics contributes to the society of researchers in other fields, as it facilitates new developments in those fields. The literature contains some examples of multi-disciplinary work in which physics students participated, on open-ended problems towards the end of engineering bachelor programs (so-called Capstone projects [8]). This indicates that there are likely to be opportunities to define challenges relevant to society, which are suitable for mathematics and physics students, if the specific nature of these subjects is taken into account.

However, the introduction of CBE in mathematics and physics is not only a matter of identifying suitable challenges. It also constitutes a curriculum change in the departments, in which several factors play a role.

2.2 Successful change in engineering education

Lattuca and Pollard [9] have identified different influences relative to curricular change: external influences (e.g. quality assurance systems, workforce needs), internal influences (at the institution and department level), and individual influences (e.g. experiences, knowledge, attitude and beliefs; see also [10]). They contend that these influences motivate decisions to engage in curricular change. They have also noted that disciplinary cultures (at the departmental level) often influence faculty commitment to change and decision-making practices.

Actors associated with curricular change are in particular (1) the *stakeholders* – those individuals or groups who have vested interest and/or involvement in or are impacted by curricular change; and (2) the *change agents* – those individuals or groups who are charged with the implementation of the change. These include department chairs, curriculum committees, individual faculty members, and groups of individuals.

The context and actors, it is said, ultimately shape the success of curricular change. Features that support successful curricular change can be termed as success factors, and those that account for unsuccessful curricular change as barriers. In her extensive international study of educational change in engineering education, Graham [4] identified common success factors and barriers, divided into four categories: (1) the context for change (e.g. upcoming institutional/sector-wide change); (2) leadership and faculty engagement (e.g. explicit support from university management); (3) educational design and implementation (e.g. a “unique” educational approach); (4) sustaining change (e.g. improvement in student intake quality and motivation). Graham also identified barriers to successful change, such as: insufficient resources to sustain the reforms; over-reliance on a small number of individuals; strong student or faculty dissatisfaction. We have used these factors as an analytic frame for the analysis of our data (see below).

3 CONTEXT

The university where this study took place has a educational vision in which CBE plays an important role. Several university departments have been creating opportunities for student learning based on the principles of CBE. A university-wide task force has been established to oversee the CBE-related education and research efforts, to identify promising educational practices for a curriculum based on CBE, and to facilitate integrating CBE in the departmental curricula.

One of the CBE initiatives has been the opportunity for students to conduct their obligatory Bachelor Final Project in an innovation lab at the university (the IBFP). In the IBFP groups of 4-5 bachelor students work together in multi-disciplinary teams (e.g. industrial design, mechanical engineering, innovation sciences and physics) on a challenge, set by an external stakeholder. This setup provides students with opportunities to investigate an authentic situation, identify and select a particular problem to work on, and develop a (prototype) solution.The educational directors of the university departments decide which challenges are suitable for their students. The students have to fulfill the Bachelor Final Project requirements set by their respective disciplines and departments. Communication with the students about IBFP takes place both by the departments and by the innovation lab. Each student group has a coach and a tutor from the innovation lab, as well as the outside stakeholder, who support the collaboration process and guide the projects. Moreover, each student has an academic coach from his/her department, who supports the student regarding disciplinary content. After it had become clear that (practically) no students from the physics and mathematics departments had participated in IBFP, a study was commenced to investigate why this was the case and how IBFPs could be made more attractive for these students. In this paper we report on the first part of the project: to understand the absence of physics and mathematics students in IBFP.

4 METHODOLOGY

4.1 Participants and data collection strategies

Using a qualitative approach, we conducted an exploratory study, involving semi-structured interviews and content analysis of university documents to answer the research questions. We individually interviewed 13 respondents involved with IBFP: the CBE task force leader, coordinators and educational directors from the mathematics and physics departments, an academic supervisor from the department of mechanical engineering, and managers, coordinators and a researcher from the innovation lab. We also interviewed a physics student doing the IBFP and his academic supervisor.

The topics addressed in the interviews concerned the following: the content of the challenges and their suitability and attractiveness for physics and mathematics students; supervision and coaching; the context, views and policies around CBE, Bachelor Final Projects and IBFP; organizational issues (e.g. communication, alignment).

In terms of university documents, we studied the relevant study guides and assessment documents, and university websites containing communication to students, including challenge descriptions.

4.2 Analysis

Following a grounded theory approach [11], the interviews were transcribed and we, (the first and second author) independently coded the complete set of interviews. We used the interview topics as sensitizing concepts, and adding codes based on our interpretation of the data. We then compared our results and discussed all discrepancies until an agreement was found. This resulted in a total of 248 interview quotes connected to 14 codes. For each code, the quotes were identified as affordances or constraints to IBFP participation. Subsequently we compared the codes and their quotations and found we could group them into three themes, related to: (a) the content of the challenges and the CBE approach, (b) the students and university faculty, and (c) the departments and the university as a whole. We then wrote summary descriptions of the affordances and constraints for each theme, which we verified against the interview data.

In the second part of the analysis we used the summary descriptions to connect each of the affordances and constraints with the success factors and barriers from Graham's framework [4] in order to answer the second research question.

5 RESULTS

5.1 Affordances and constraints

We present a summary of the affordances and constraints we identified for each of the three themes (Table 1). Space does not allow for a full elaboration of the results.

Table 1. Affordances and constraints for the participation of mathematics and physics students in IBFP

A/C[1]	Description
Theme 1: the content of the challenges and the CBE approach	
A1	Respondents had experienced that the challenges allowed students from different departments to show their disciplinary knowledge and skills.
A2	In some challenges, respondents from the physics department saw "sufficient physics" for successful participation of physics students.
A3	Respondents from the physics and mathematics departments saw potential benefits for students in the CBE approach (e.g. "to see mathematics at work", "to work in multidisciplinary groups").
C1	Respondents from the mathematics department found it difficult to see how the challenges could lead to a mathematics project of sufficient depth.
C2	Given the broad challenge descriptions, respondents from the physics and mathematics departments expected that students (and coaches) might not be able to recognize how they could contribute using disciplinary knowledge.
Theme 2: the students and university faculty	
A4	Respondents expected that IBFP would appeal to those mathematics and physics students interested in engineering, design, and collaborative work.
A5	Respondents expected that coaching IBFP students would appeal to part of the mathematics and physics faculty.
C3	Respondents expected that lack of earlier (positive) collaborative group work experiences could discourage mathematics and physics students to apply to IBFP.

C4	Respondents expected some faculty to feel uncomfortable coaching IBFP, for reasons of workload, perceived lack of required expertise, and difficulties to apply the departmental assessment criteria.
Theme 3: the departments and the university as a whole	
A6	Mathematics and physics educational directors indicated that they supported the participation of their students in IBFP, provided certain conditions were fulfilled.
A7	The innovation lab emphasized communication with the departments in order to (a) define suitable challenges, and (b) attract students.
A8	At senior management level, the university, supported the introduction of CBE, including the multidisciplinary IBFP.
C5	The organization and communication within the departments and between the departments and their students had not been aligned with IBFP requirements.
C6	There had been few collaboration experiences between the mathematics and physics departments and the innovation lab. As a results, the innovation lab hardly had any “ambassadors” in the departments to foster CBE opportunities such as IBFP.

Notes: [1]: A: Affordance; C: Constraint

5.2 Factors affecting curriculum change

We compared the affordances and constraints from Table 1 to the framework of factors associated with successful (and unsuccessful) curriculum change [4]. The results show that some success factors could clearly be identified in the IBFP developments for physics and mathematics. However, the constraints implied that several success factors were present only to a limited extent, or not at all (Table 2).

Table 2. Affordances and constraints for the participation of mathematics and physics students in IBFP

Framework description	A/C[1]	Interview data
Factors positively related to successful curriculum change		
Faculty agree change is necessary, due to issues “in the market”.	A3	Students could develop relevant engineering skills in IBFP, not generally offered by the departments.
Support from senior management; balance of top-down and bottom-up pressures.	A3, A6, A8	IBFP was in line with university policies regarding CBE. The attitudes of the task force leader, the departments (with reservations) and the innovation lab were positive.

The changes are a core and integrated element of a coherent curriculum structure.	A2, C1, C3, C4, C5, C6	IBFP was not yet in line with the core mathematics and physics curricula. Students had had relatively few CBE experiences. Departmental procedures and communication were not in line with IBFP participation.
High proportion of faculty involved in the (design of) the curriculum change.	C2, C6	Mathematics and physics faculty not had not been involved in the process of formulating IBFP challenges. Absence of “ambassadors”.
There is no pressure on reluctant faculty to participate in the change.	A5	Directors and coordinators showed awareness that interest to coach IBFP would be with part of the faculty only.
The change leads to an improvement in student intake and motivation.	A1, C2, A4, A7	A number of physics and mathematics students were expected to benefit from IBFP. The innovation lab’s activities aimed at increasing student intake from different departments.
Factor negatively related to successful curriculum change		
Faculty “revolt” against the change, e.g. because they fear a “dumbing down” of the curriculum.	A1, C1,	The physics department did *not* expect that IBFP would lead to a lower level of student work (no “dumbing down“). For mathematics there was a concern that their students would be used for “doing calculations”.

Notes: [1]: A: Affordance; C: Constraint

6 SUMMARY

Based on our interviews and document analysis, we found affordances and constraints that stakeholders perceived for mathematics and physics students to choose and participate in IBFP. We argue that important conditions for participation of these students have been fulfilled at the university: there is top-down and bottom-up support and it is likely that the IBFP will appeal to part of the students and faculty.

We also found important short term and long term constraints. There is a need for challenges with sufficient mathematical (and to a lesser extent physical) depth, or even: a need for design principles regarding such challenges. To this end, involving mathematicians and physicists in the process of defining challenges may prove helpful. There are practical communication and organizational issues that would need to be solved. The limited opportunities physics and mathematics students have had in the bachelor programme to engage in open-ended collaborative projects might be a constraint to their participation in IBFP.

The introduction of CBE and IBFP has signified a still ongoing change in the curriculum of the physics and mathematics departments. In terms of Graham’s framework [4], the support IBFP has received at various levels in the university is promising for its success. However, to ensure its success for mathematics and physics students, challenges need to be designed in line with the disciplinary demands of these subjects. Moreover, in the long term, the integration of more CBE into the departmental curricula might foster IBFP as a feasible option for interested students, similar to the departmental Bachelor final Projects. Finally, collaboration between departments in the light of a curriculum change can be demanding for those involved. It is expected that an increased sense of ownership for the development towards CBE will develop, when more mathematics and physics faculty and students become involved in the innovation lab, the creation of challenges, and IBFP [10].

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